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AN INVESTIGATION OF MULTISENSOR PRECIPITATION ESTIMATES (MPE) AND OPERATIONAL USE OF MPE AT THE MIDDLE ATLANTIC RIVER FORECAST CENTER (MARFC)

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Abstract

There were three main reasons the Middle Atlantic River Forecast Center (MARFC) decided not to implement the Multisensor Precipitation Estimate (MPE) program into daily operations as soon as it was made available. First, MARFC has a relatively dense precipitation gage network, approximately one hourly gage per 139 square miles. Second, the hydrologic model used at MARFC was calibrated using gage-only MAP values as opposed to radar and gage derived mean areal precipitation values or MAPXs. Finally, there was a concern about the validity of MPE data and the potential discontinuities between the MAPs and MAPXs. However, MPE is available for operational use and is being used for Quantitative Precipitation Forecast (QPF) verification and by external users on a daily basis. Therefore, MARFC recognized the need to begin an investigation in order to evaluate workload issues, the quality of the data being provided, and the validity of using this data in operational hydrologic forecasting. A variety of analyses occurred: MPE data was quality controlled during the workload assessment, MPE data was obtained and analyzed by grid point and area values, and MAPX (radar and gage derived mean areal precipitation values) data was tested within the hydrologic model used at MARFC. The results of this study has led to some operational use of MPE and identified the need for further investigation concerning its use in operational hydrologic models.

1. INTRODUCTION

With the advent of the National Oceanic and Atmospheric Administration (NOAA)/ National Weather Service's (NWS) Weather Surveillance Radar-1988 Doppler (WSR-88D), it became possible to routinely obtain high resolution estimates of precipitation in locations void of gage data. The River Forecast Center-wide multisensor precipitation estimator (RFCWide) and its predecessors, the precursors to multisensor precipitation estimate (MPE), were delivered and installed at MARFC beginning in 1999 and with them came the ability to evaluate estimated precipitation for each 4 by 4 kilometer grid area within the MARFC area of responsibility. MPE gives the user the opportunity to use radar derived precipitation amounts, gage only amounts, or a combination of radar and gage hourly amounts (MAPX) to calculate a mean areal precipitation. MARFC benefits from a relatively dense hourly gage network (Table 1), but has an interest in utilizing MPE data to enhance forecast operations. Therefore, in 2001, MARFC began investigating the workload impacts of this new program and the quality of the MPE derived precipitation data.

An office team was created to investigate the validity of the MPE data and make recommendations on how it should be incorporated into MARFC operations. To accomplish this, the investigation was divided into four major sections: workload assessment, point assessment, areal assessment, and operational use in river forecast models. Team members evaluated these four sections and provided results and recommendations.

2. DATA, METHODOLOGY and RESULTS

a. Workload Assessment

The goal of this assessment was to determine the operational impact on the Hydrometeorologic Analysis and Support (HAS) forecaster in using the MPE interface for quality controlling data and creating the final XMRG (hourly gridded precipitation file format) file.

1) Data Collection and Analysis

RFCWide was the predecessor to MPE and allowed for a forecaster to edit or quality control (QC) the hourly XMRG files. The MPE graphical interface provides the user with an array of editing choices. First, a user can decide to start with the derived MPE multisensor field, gage-only field, or radar-only field. If the user is satisfied with one of those fields, the file can be saved as the final XMRG image for the given hour. However, the user can also make edits to any field by changing the gage table, radar bias, drawing polygons and assigning a precipitation value to the entire area, or ignoring data from individual radars.

The first workload evaluation process was performed over a six month period beginning in July 2001. At this time only one forecaster was performing the evaluation and completed approximately 100 complete editing sessions, editing 24-hours of data at a time. Also, at this time MARFC developed an “auto QC” procedure. This procedure removes any precipitation gage value that the HAS forecaster determines to be inaccurate and excludes that value from the list of candidate gages for subsequent hourly bias calculations.

From May 2003 through December 2003, the workload evaluation process was repeated. During this analysis four forecasters were trained to use the MPE interface. Each day one of the four forecasters edited 24-hours of data, and by December 2003 a total of 186 editing sessions were completed. During both evaluation periods, forecasters documented the time necessary to complete all manual quality control actions and what type of quality control actions were processed. The evaluation process was repeated again in February 2004 by two forecasters, when MARFC operations were converted from the HP platform to the Linux platform.

2) Results

During the first analysis of RFCWide (July – December 2001), it took the forecaster an average of 25 minutes to manually quality control a 24-hour period of data. If the forecaster made an edit to the gage table, then RFCWgen (program which generated gridded fields) had to be rerun. Rerunning RFCWgen took approximately three minutes to complete. It also became apparent that season and precipitation type played a key factor in how long the entire process would take. During the warm season when convective activity is more likely, the decision process took longer as compared to the cool season when stratiform events provided for more uniform areal coverage and precipitation amounts, and required less decision making time. Although decision making added time to the process, the actual computation was the largest time requirement.

During the second analysis of MPE (May – December 2003), there where four forecasters to perform the analysis, the results were similar to the first analysis for all forecasters. On average, forecasters were spending 25 minutes to edit a complete 24-hour period.

During the third analysis of the MPE program in February 2004, completion times improved dramatically due to the conversion from the HP to the Linux platform and the test ceased after one week. Forecasters could complete a 24-hour period in five minutes for a non-precipitation event and on average ten to fifteen minutes when precipitation had occurred. With the installation of the Linux operating system the workload associated with editing 24-hours of data at once was no longer a concern due to the increase in processing power.

b. Point Assessment: Independent Gage Value vs. MPE Grid Area Value

The goal of the independent gage versus MPE grid study was to assess the validity of the MPE data produced.

1) Data Collection and Analysis

Archived MPE data are stored in hourly XMRG files. XMRG files were obtained for the period 1 January 2002 to 31 December 2004 from MARFC's data archive and from the NWS Office of Hydrologic Development. The hourly data were then converted to hydrologic daily data, which is defined as the 24-hour period ending 12 UTC.

Gages that were not used in MPE calculations were sought out to make independent precipitation gage to MPE grid comparisons. Reliable cooperative observers with a minimum 90% reporting frequency were identified and a subset was selected to represent a variety of characteristics such as: elevation, distance from radar(s) and location within MARFC area of responsibility (Fig. 1). For the time period of 2 January 2002 through 30 January 2003, there were four cooperative observer locations selected. From 1 February 2003 through 31 December 2004, there were 25 gages selected. Although the 21 additional gages used from 1 February 2003 to 31 December 2004 were included in MPE calculations from 2 January 2002 through 30 January 2003, gage to grid comparisons were still made using these 21 gages.

After the independent gages were identified, the corresponding 4 by 4 km Hydrologic Rainfall Analysis Project (HRAP) grid location was identified and the MPE value assigned to that grid location was extracted. Next, both the MPE values and the independent gage values were imported into Microsoft Excel.

Once the data was imported into Excel, double mass curves were developed for each year from 2002 – 2004. Double-mass analysis of grid and gage data allowed for easy comparisons of accumulated precipitation on a yearly basis (Fig. 2). At the end of the year for each location the annual accumulated MPE grid values versus accumulated gage ratio was determined by dividing the accumulated MPE grid value on the last day of the year by the gage accumulation for the last day of the year. A value less than 1 meant the MPE grid accumulation was less than the gage value (MPE underestimate) and a value above 1 meant the MPE grid value was more than the gage value (MPE overestimate). These values were then converted to percentages.

2) Results

As can be seen from Table 2, on average, the MPE grid accumulation for the years 2002 and 2003 was 92% and 89%, respectively, of the MAP accumulation. In 2004, the average increased to 98% of the MAP accumulation, which indicated that something may have changed to alter either MAP or MPE calculations in late 2003 or early 2004 to cause such a dramatic improvement in 2004. Since no changes were made to either of MARFC's MAP or MPE calculation process, nor were any gage locations moved during this time frame, the WSR-88D's precipitation processing system was analyzed to see if any changes were made during the late 2003 to early 2004 time period.

It was learned that during Radar Products Generator (RPG) Build 4, which was performed at radars influencing MARFC's MPE calculations from October 2003 through June 2004, a change was made to the precipitation processing system. According to the Warning Decision Training Branch's documentation for RPG Build 4,

> "The process of accumulating rainfall in the Precipitation Processing System (PPS) includes a slight truncation error, which can have a cumulative effect and cause underestimates of rainfall. The problem is most significant for sustained, light precipitation events and is most apparent on hourly-based products (One Hour, Three Hour, and User Selectable Precipitation, and the Digital Precipitation Array). A correction to this problem is included in RPG Build 4, with more accurate hourly products during light rainfall events to be expected" (National Weather Service 2003).

It appears that this change has improved MPE values as compared to the independent gages for many locations. For example, in 2002 and 2003 Slide Mountain, NY (SLDN6) MPE values were 79% and 74% of the gage values respectively, but in 2004 the MPE value improved to 88% of the gage value. In November 2003 the radars that have the greatest influence on SLDN6, KENX and KBGM, performed the RPG Build 4 upgrade. Figure 3 indicates that once the RPG upgrade was made the accumulated difference (gage – grid) over time decreases as soon as the change was made. This is apparent by visually comparing the slope of the line prior to the RPG Build 4 upgrades to the slope of the line after these upgrades were performed. This improvement was also seen at five of the seven locations investigated.

Individual locations which are underestimating radar-derived precipitation can be in part attributed to topography, such as Romney, WV (ROMW2), beam blockage and/or rain shadows. There are also locations that consistently overestimate radar-derived precipitation as compared to the comparison gage, such as Gathright Dam (GDMV2). Overestimation may occur due to precipitation type and bright banding increasing returns which can be overlooked during the MPE editing process if they are buried in actual high returns.

c. Areal Gage Assessment: MAP Values vs. MAPX Values

In contrast to the independent gage vs. MPE grid assessment, comparing MAP and MAPX values focused on determining the existence of any consistent biases when compared to existing gage-based areal averaging methodologies. If not identified and accounted for properly, such biases could have adverse impacts on the validity of operational forecast routines and water supply information that are based on areal averaged historical gage data.

1) Data Collection and Analysis

Basin MAPs, based on gage-only data, are computed by the Operational Forecast System (OFS) in six-hour time steps. One hundred forty-five quality controlled and archived MAPs were summed into annual totals for calendar years 2003 and 2004, both generally wetter than average years across the MARFC area. The analogous basin MAPXs, derived from hourly MPE data, were summed as well over the same time periods, and compared to the MAPs in the form of annual ratios (Fig 4 and Fig 5). It should be noted that MARFC's MAPXs are enhanced with a locally developed methodology that estimates the hourly time distribution of cooperative observer data, arguably the most consistently reliable and geographically diverse precipitation gage network (a similar process has since become available as an MPE post analysis application, but MARFC still uses its locally developed application). Cooperative reports are typically received each morning between 7am and 9am from as many as 250 locations (normally a subset of 100-150 reports are available on any given day). These daily reports are disaggregated into hourly amounts based on the corresponding ratios of hourly versus 24-hour precipitation computed by the MAPX process for the same 24-hour time period and area containing the cooperative station. The estimated hourly cooperative precipitation is then SHEF encoded and fed back through the MPE process, and the hourly biases recomputed for the previous 24 hour period.

2) Results

As can be seen from Fig. 4, the 2003 annual MAPX/MAP ratio for the vast majority of MARFC basins was less than 1.00, meaning that MAPXs were generally lower than the corresponding MAPs. The average MAPX/MAP ratio for all basins was 0.89 or 89% of the MAP value in 2003, though there was considerable geographic, topographic, and seasonal variability. In general, the MAPX/MAP ratio was larger in winter and in areas affected by terrain-induced beam blockage. Figure 5 depicts the 2004 annual MAPX/MAP ratios. While the overall geographic pattern of values was similar to the 2003 data, the magnitude of the MAPX/MAP ratio had consistently diminished. The average MAPX/MAP ratio for all basins had improved to 0.97 or 97% of the MAP value in 2004, and in 49 of the 145 basins, MAPX was equal to or greater than the corresponding MAP, compared to only 4 of 145 basins in 2003. Since the methodology and data sources for the MAP calculations were essentially unchanged through 2003 and 2004, and the meteorological patterns remarkably similar through the period, it is reasonable to conclude the reason for the reduced MAPX/MAP ratios in 2004 is related to a change in the MAPX methodology or data. This is consistent with similar findings in Section 2b above, the Point Assessment. The only known change is the upgrade to the radar PPS system previously discussed.

d. Operational Forecasting MAP vs MAPX

The goal of this test was to compare the use of MAPs and MAPXs in hydrologic model simulations.

1) Data Collection and Analysis

MARFC uses the Continuous Antecedent Precipitation Index (API-Continuous) hydrologic model within the National Weather Service River Forecast System (NWSRFS) for forecast operations. Operational MAPs are calculated at 12 UTC each day on a 6-hr time step with gage data that has been quality controlled by the HAS forecaster. MAPXs were calculated from

OFS using quality controlled hourly MPE data, which also included time-distributed cooperative observer data. These hourly data were summed to form 6-hour time series for use in the hydrologic model.

From June 2001 to February 2004, two hydrologists tested both MAPs and MAPXs on two geographically distinct basins. The first location chosen was the Raritian River Basin (RTN) in New Jersey (785 square miles) which consists of rolling hills and coastal plain. The second location chosen was the Juniata River Basin (JUN) located in the mountains of South Central Pennsylvania (3354 square miles). Both locations have good radar coverage (Fig. 6). These two forecast groups, consisting of several sub-basins, were run in a test mode (at forecast time) with the SWITCH-TS operation made available to the forecaster. This operation allowed the forecaster to switch precipitation inputs used in the hydrologic model from the MAP to MAPX time series. Each segment within the RTN and JUN river basins was then run with both the MAP and MAPX time series to see which values made the most accurate simulations. The results were then analyzed and then the basins were compared to each other. Precipitation type (convective or stratiform) and intensity of the event (light, moderate or heavy) were also noted. Each forecaster kept a log of their results and determined if they would have obtained more accurate simulations using MAPs or MAPXs. This was a subjective analysis due to the changing runoff efficiencies based on the seasons. For example, a “moderate” event during the winter months may only be a “light” event during the summer months.

2) Results

For the period analyzed, June 2001 through February 2004, the overall results by basin can be found in Table 3. Although there is not much difference when comparing the Juniata and Raritan Basins by location, on about 40% of the test runs both basins did perform better when MAPs were used as opposed to MAPX. Over one third of the time the forecaster could not determine if the MAP or MAPX was the better choice for a given event. Forecasters also kept track if the event was convective or non-convective. As indicated in Table 4, MAPXs were slightly better for convective events compared to non-convective events, but even in convective events MAPs still performed better over MAPX.

3. CONCLUSION

Although MARFC was not using MPE data operationally, the data was being provided to and used by external users. Hourly MPE data is also being used for verification of MARFC’s QPF. This investigation was necessary in order to evaluate workload issues, the quality of the data being provided in MARFC’s area of responsibility, and the validity of using this data in operational hydrologic forecasting. With the introduction of the Linux platform the editing of 24-hours of data at one time is no longer a concern due to the increased processing power. This process has become part of the operational routine of the HAS forecaster.

Evaluating the point 2002 and 2003 data there was, on average, a 10% low MAPX/MAP ratio of the MPE data as compared to the independent gage data. It appears that when RPG Build 4 was performed on the WSR-88Ds, correcting a truncation error in the PPS, the MAPX/MAP ratio, on average, improved to a 2% low MAPX/MAP ratio. This improvement is promising but does raise some concerns. Since the radars are upgraded regularly it is important that the RFC community be informed of changes that will directly effect how the radar estimates precipitation. Due to the dynamic nature of radar algorithms

MARFC will continue to compare independent gages to the MPE grid data. Further investigation is needed to study why some individual locations consistently overestimate precipitation.

Also, when evaluating the MAPX/MAP annual areal ratios in 2003, on average the majority of MAPX/MAP ratios for all basins were an 11% low MAPX/MAP ratio. These results are similar to the results of the point gage comparison. On average, 2004 data improved to a 3% low MAPX/MAP ratio. MARFC will continue to monitor and investigate basin MAPXs.

Finally, the use of MAPXs in the hydrological models for the Raritan and Juniata River basins, in most cases, did not improve model simulations. Further investigation of these two basins is warranted at this point since the MPE data did improve in 2004 and the forecasting investigation ceased in February of 2004. Also, repeating the operational forecasting tests in basins where the MPE data is consistently within a few percent of the independent gage data may also prove to be beneficial.

However, there is the underlying fact that the API-Continuous model that MARFC uses has been calibrated using MAP data. Ideally, before MAPX data are used operationally the model should be recalibrated using historical MAPX data. Since we are documenting our results, the data collected may be used in the future to adjust MAPX data to one day calibrate MARFC's hydrological models.

There were three main reasons MARFC decided not to implement the MPE program into daily operations as soon as it was made available. First, MARFC has a relatively dense precipitation gage network, approximately one hourly gage per 139 square miles (Table 4). Second, the hydrologic model used at MARFC was calibrated using gage-only MAP values as opposed to radar and gage derived mean areal precipitation values or MAPXs. Finally, there was a concern about the validity of MPE data and the potential discontinuities between the MAPs and MAPXs.

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REFERENCES

National Weather Service, Warning Decision Branch, cited 2003: RPG Build 4 Training. [Available on-online at: http://www.wdtb.noaa.gov/modules/RPG4/build4training.pdf]

Figures

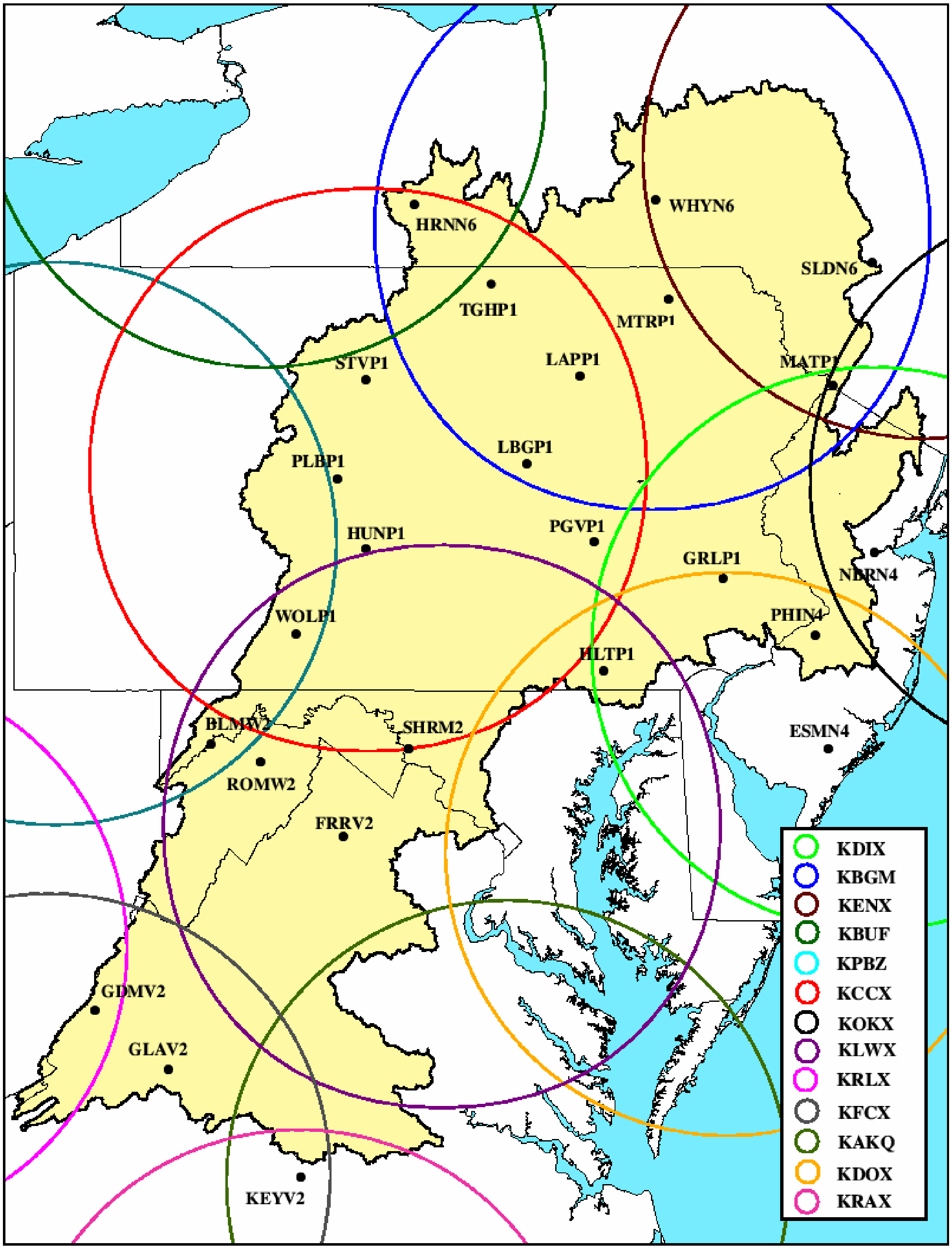

Figure 1. Independent gage locations used in this investigation and the radar rings located within the MARFC area of responsibility. Radar rings are color coded according to the legend. The shaded area (yellow) is the MARFC area of responsibility.

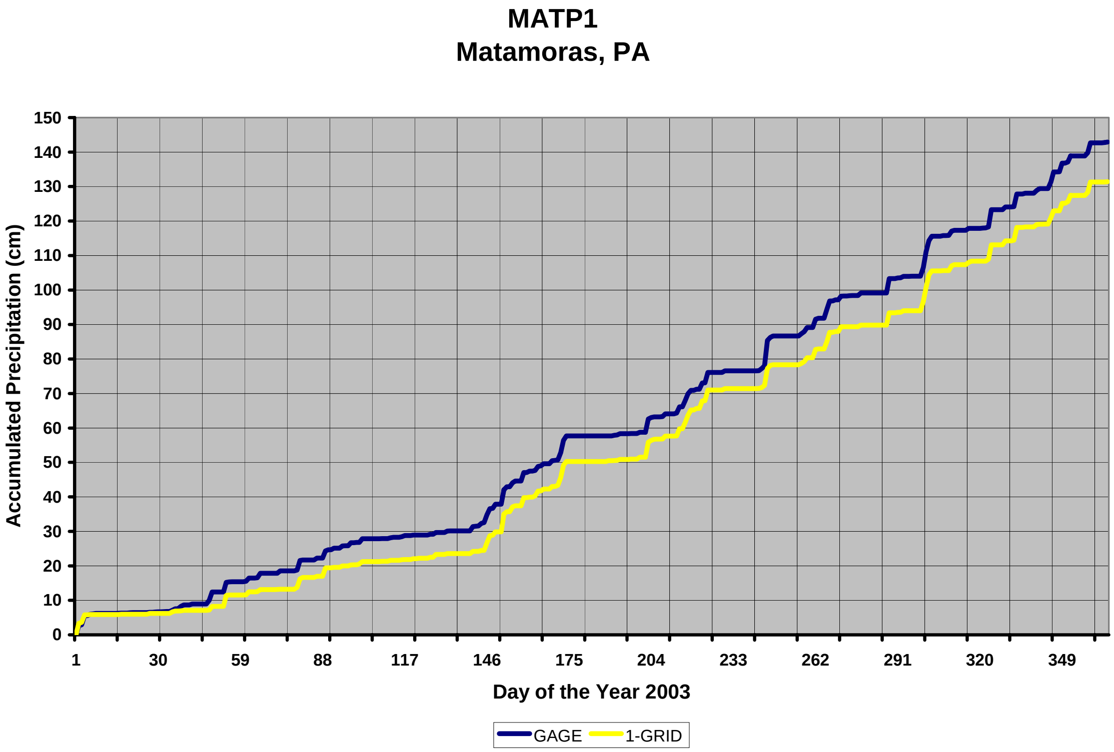

Figure 2. A double mass analysis of gage and grid data for Matamoras, PA (MATP1) for 2003.

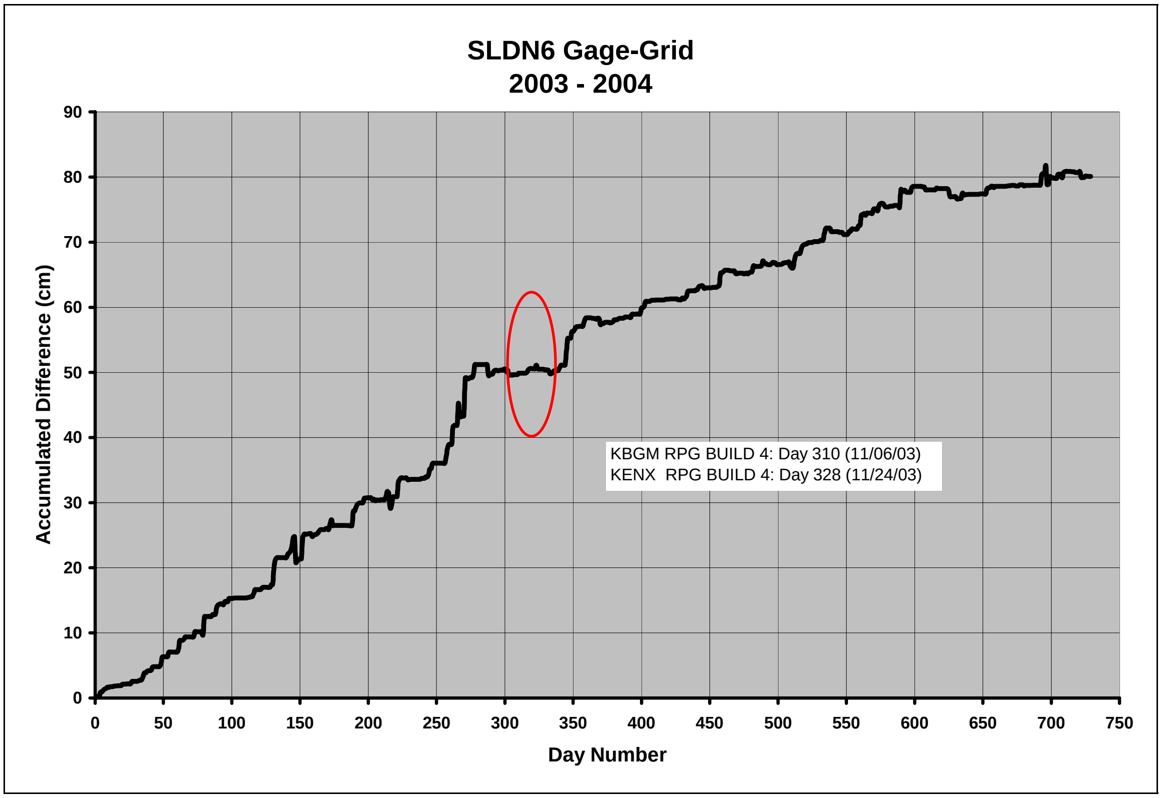

Figure 3. Accumulated difference (gage – grid value in cm) over 2003 – 2004 for Slide Mountain, NY (SLDN6). The red circle indicates when the RPG build 4 was performed.

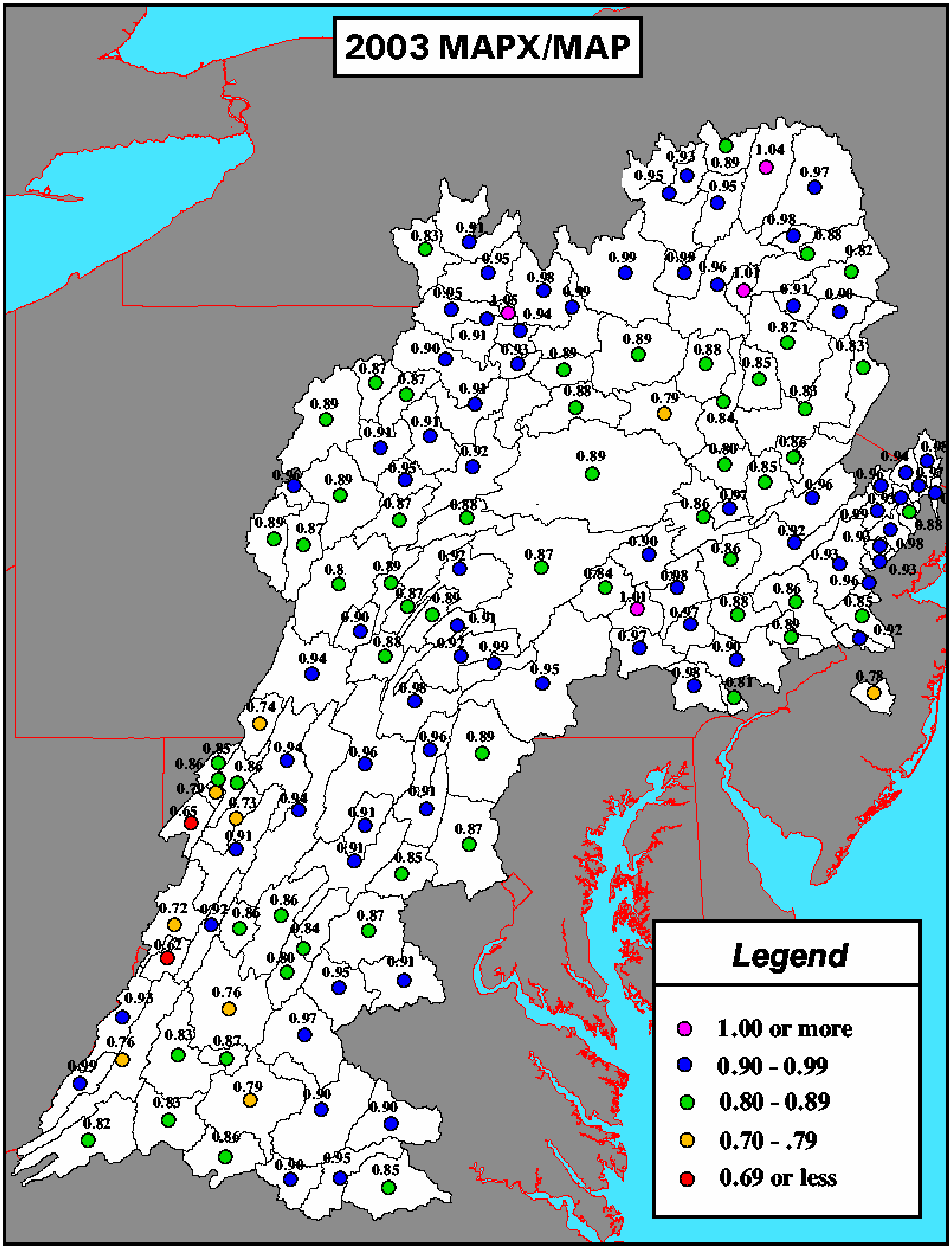

Figure 4. 2003 MAPX/MAP for MARFC area of responsibility.

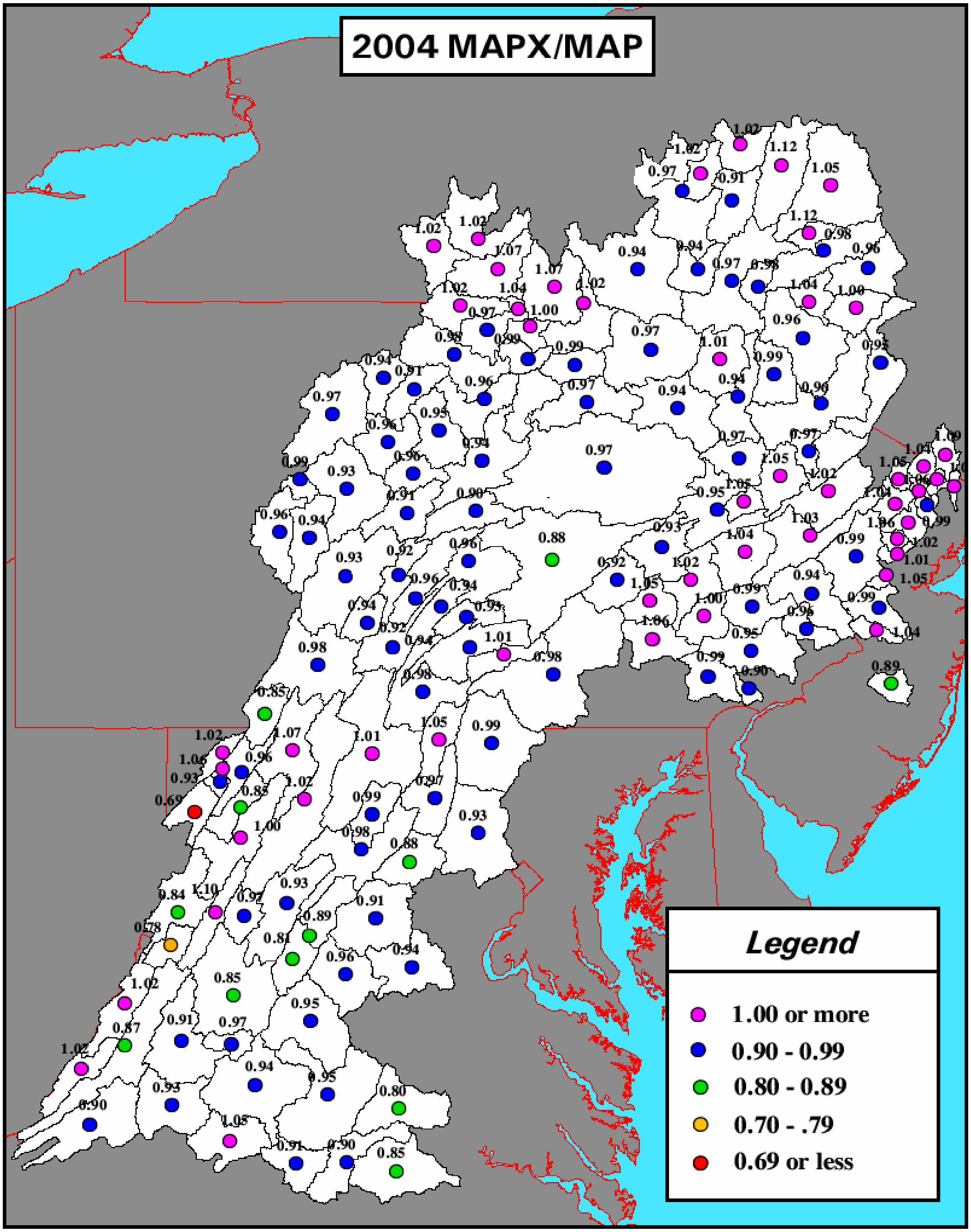

Figure 5. 2004 MAPX/MAP for MARFC area of responsibility.

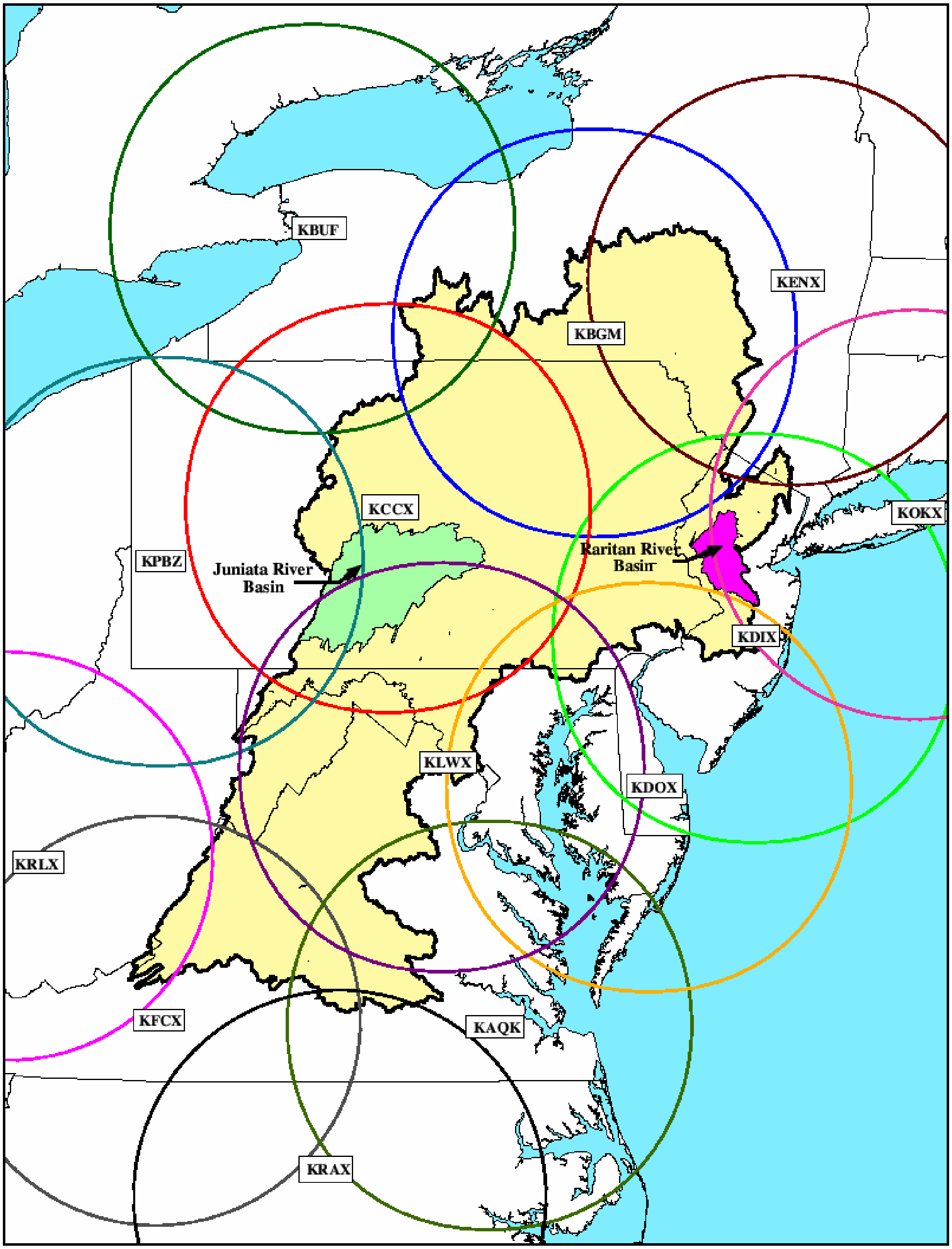

Figure 6. MARFC basins used in operational forecasting investigation with radar rings (same color coding as in Fig.1) which have an influence on MARFC's area of responsibility (shaded yellow). The Raritan River Basin is in pink and the Juniata River Basin is in green.

Table 1. NWS RFC Hourly Precipitation Survey as of September 2004. Gage data was provided by each RFC and total area was provided by the Office of Hydrologic Development. The far right column indicates the total area of the RFC divided by the approximate number of hourly gages within the RFC area of responsibility.

Survey of NWS RFC Hourly Precipitation Gage Density September 2004			
RFC	**Total Area (mi^2)**	**Hourly Gages**	**Ratio (mi^2/gage) or One Gage per "X" mi^2**
OHRFC	175779	1299	135
MARFC	82638	595	139
LMRFC	203967	1200	170
CBRFC	306278	1397	219
CNRFC	249758	1000	250
NWRFC	314271	1222	257
SERFC	249050	965	258
ABRFC	210341	700	300
NERFC	104856	327	321
MBRFC	520979	1500	347
NCRFC	339440	880	386
WGRFC	311920	700	446
AKRFC	589569	236	2498

Table 2. MPE grid total precipitation/Gage total precipitation for each location from 2002-2004. * indicates gages which were not included in MPE calculations from January 2002 through December 2003. All other gages were removed from MPE calulations beginning February 1, 2003. ** indicates gages which were further investigaged in 2004 and the relationship to RPG Build 4.

	YEAR		
GAGE NAME	**2002**	**2003**	**2004**
BLMW2	0.86	0.85	1.02
*ESMN4	0.82	0.88	0.83
FRRV2	0.80	0.95	1.01
**GDMV2	1.04	1.11	1.22
GLAV2	0.89	0.82	0.92
**GRLP1	1.02	0.91	1.05
*HLTP1	0.88	0.89	0.98
**HRNN6	0.86	0.79	1.01
HUNP1	1.07	0.82	0.94
**KEYV2	N/A	0.97	0.97
**LAPP1	0.83	0.80	0.89
**LBGP1	1.00	0.93	0.98
MATP1	0.90	0.92	1.01
MTRP1	0.89	0.96	0.96
*NBRN4	0.99	0.82	1.03
PGVP1	0.74	0.81	0.89
PHIN4	0.96	0.90	1.03
**PLBP1	0.99	0.91	1.02
**ROMW2	0.71	0.72	0.70
**SHRM2	1.03	0.99	1.01
**SLDN6	0.79	0.74	0.88
*STVP1	0.97	0.97	1.02
TGHP1	1.02	0.95	1.08
WHYN6	1.01	1.08	1.03
WOLP1	0.98	0.88	0.96
AVERAGE	**0.92**	**0.89**	**0.98**

Table 3. MAP vs MAPX during operational forecasting, June 2001 – February 2004. Numbers indicate fraction of total forecasts where forecaster determined one precipitation source resulted in more accurate hydrologic simulations. No Preference means that an equal amount of the segments within a basin where favoring MAP or MAPX for a given event.

Operational Forecasting MAP vs MAPX		
	Juniata River Basin (n=195)	**Raritan River Basin (n=177)**
MAP	0.42	0.40
MAPX	0.24	0.24
No Preference	0.34	0.36

Table 4. MAP vs MAPX during operational forecasting noting precipitation type, June 2001 – February 2004. Numbers indicate fraction of total forecasts where forecaster determined one precipitation source resulted in more accurate hydrologic simulations No Preference means that an equal amount of the segments within a basin where favoring MAP or MAPX for a given event.

Operational Forecasting MAP vs MAPX		
	Convective Events	**Non-Convective Events**
MAP	0.43	0.51
MAPX	0.27	0.18
No Preference	0.30	0.32